The Application of GOCE Satellite Gravity Data for Basin and Petroleum System Modeling: A Case-Study from the Arabian Peninsula*

R. Abdul Fattah[1], J. A. C. Meekes[1], S. Colella[1], J. Bouman[2], M. Schmidt[2], and J. Ebbing[3]

Search and Discovery Article #120130 (2013)
Posted March 13, 2013

*Adapted from extended abstract prepared in conjunction with poster presentation at AAPG Hedberg Conference, Petroleum Systems: Modeling The Past, Planning The Future, 1-5 October 2012, Nice, France, AAPG©2012

[1]TNO, Utrecht, The Netherlands
[2]DGFI, Munich, Germany
[3]NGU, Trondheim, Norway (joerg.ebbing@ngu.no)

Introduction

The GOCE satellite gravity mission was launched in 2009 to measure the gravity gradient with high accuracy and spatial resolution. GOCE gravity data can improve the understanding and modeling of the Earth's interior and its dynamic processes, contributing to gain new insights into the geodynamics associated with the lithosphere, mantle composition, uplift and subduction processes. With careful processing and integration with additional gravimetric data, GOCE can be used to study sedimentary basins and assist in hydrocarbon exploration in underexplored areas.

In this study, GOCE gravity data is used to investigate the maturity of the main source rocks in the remote Rub' al-Khali Basin in Saudi Arabia. GOCE gravity data, in combination with other data, is used to better identify the structure and composition of the crust and the lithosphere in the region (Figure 1). The improved model of the crust and the lithosphere allow us to calculate the evolution of the basal heat flow and its spatial variations in the basin. Based on the improved heat flow model, the maturity of the main source rocks is estimated thus allowing better understanding of the petroleum systems in the region.

Application for the Arabian Peninsula

Gravity gradient data are generally sensitive to the density structure of the upper crust. Gradient data from GOCE have the potential to identify the extent of different structures with varying densities in the lower crust in the Arabian Plate. Thus, they can help to identify possible density zonation in the basement and enhance structural boundaries within the crust on a regional scale. Using the gravity anomaly maps obtained from GOCE data, in combination with land-measured gravity data, gravimetrical basement inhomogeneity and Moho topography are determined. The outcome of this phase is a model of the crust and lithosphere of the study area. This includes the thickness and composition of the crust and lithosphere.

Heat Flow Modeling and Source Rock Maturity

Data and Input Model

In addition to terrestrial gravity and GOCE gravity gradient data for assessing a model of the crust and lithosphere, information on the litho-stratigraphy of the study area is needed to build an initial geological model. Using basement depth map, well information and regional cross-sections, a geological model is constructed (Figure. 2). The resolution of the input model is adjusted to the resolution of the GOCE gravity data. Information on the evolution of the basin is required in order to construct our tectonic model required for the heat flow modeling. Boundary conditions necessary for our models (such as paleo-water depth and surface water interface temperatures) are available from published literature. Validation of the models is done using available temperature and maturity measurements in the region.

Modeling Approach

The structural model of the crust and lithosphere, obtained from the gravity data, is used for modeling the basal heat flow within the basin. We use a grid-based stochastic tool (PetroProb) developed by TNO to model basal heat flow. Our approach is based on the inversion of basin subsidence data to calculate the tectonic subsidence and tectonic heat flow of the area. It takes into account the sedimentation, erosion, and paleo-water depth history of the basin. It also incorporates the effect of sedimentation infill and heat production in the crust. The uncertainties in the crustal and lithospheric structures are included in the heat flow modeling tool. The tool allows the calibration of the model to measured temperatures and maturities in order to reduce the uncertainties in the input parameters.

The thickness, structure and properties of the crust and lithosphere are essential inputs to PetroProb. The spatial variation in the crustal stretching factor is obtained from the tectonic subsidence. Using the modeled stretching factors, the gravity-based crust is used to calculate the initial crustal thickness. This is used to model the evolution of the heat flow in the basin.

In addition, the model includes the radiogenic heat generated by radiogenic elements in the crystalline basement. Different zonations in the basement can be assigned by varying the concentration of radiogenic elements and thus varying their contributions to the modeled heat flow. The maturity of the source rocks in the basin are estimated based on the modeled heat flow and regional maturity maps are produced of the Paleozoic and Mesozoic plays in the Arabian Peninsula.

Outcome of the Study

The gravity gradient data is used to build a new model of the crust and lithosphere in the Arabian Peninsula (and the Rub' al-Khali desert). Based on that, a regional tectonic heat flow model is calculated for various geological ages. Using the heat flow maps and the geological model of the area, new maturity maps are generated for the main Paleozoic and Mesozoic source rock units in the region.

References Cited

Konert, G., A.M. Al-Afifi, S.A. Al-Hajri, and H.J. Droste, 2001, Paleozoic stratigraphy and hydrocarbon habitat of the Arabian Plate: GeoArabia, v. 6/3, p. 407-442.

Van Wees, J.D., F. van Bergen, P. David, M. Nepveu, F. Beekman, S. Cloetingh, and D. Bonte, 2009, Probabilistic tectonic heat flow modeling for basin maturation: assessment methods and applications, *in* H. Verweij, M. Kacewicz, J. Wendebourg, G. Yardley, S. Cloetingh, and S. Düppenbecker (eds.), Thematic set on Basin Modeling Perspectives: Marine and Petroleum Geology, v. 26, p. 536-551.

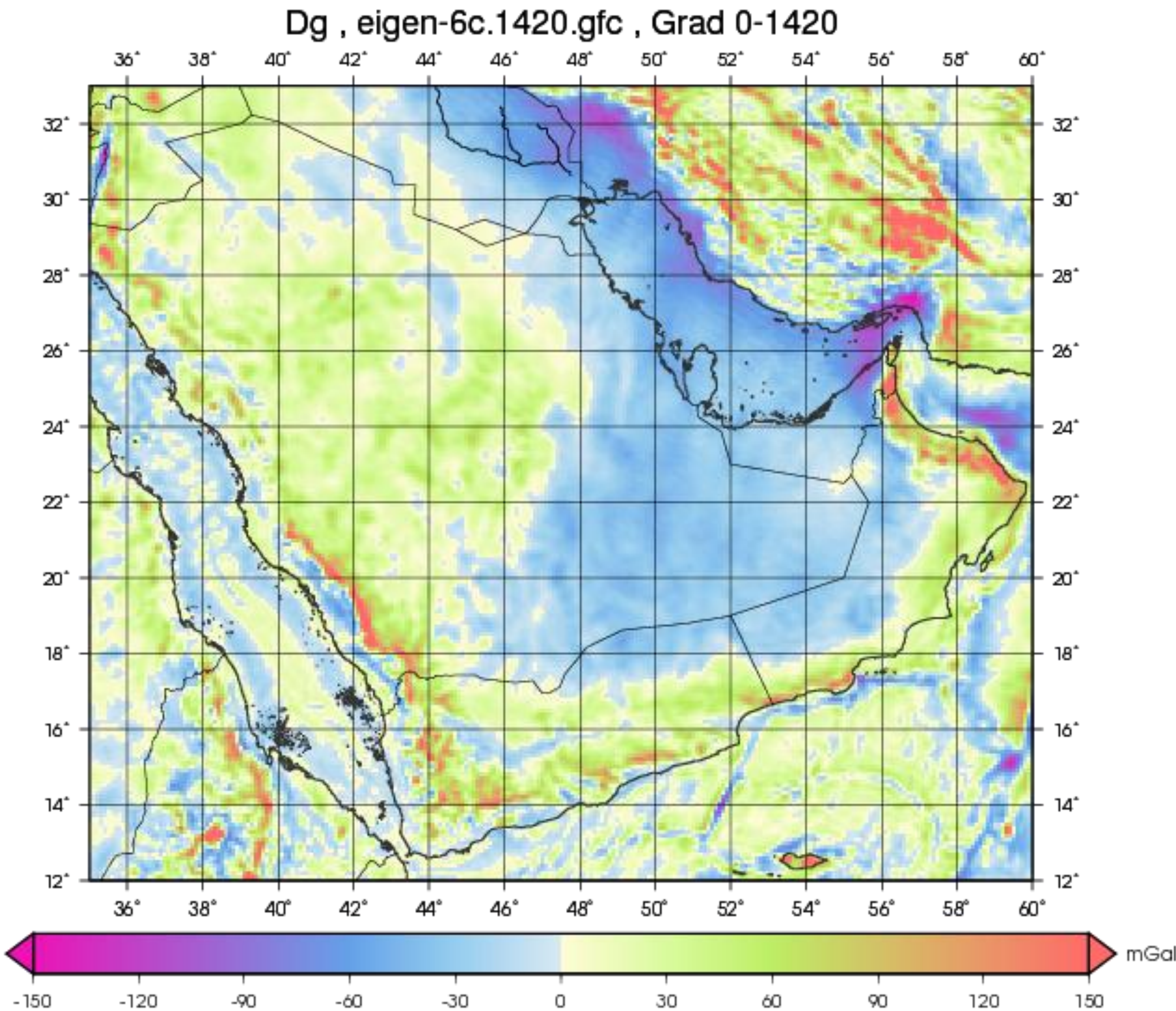

Figure 1. Gravity anomaly map of the Arabian Peninsula based on a gravity field model that combines data from GOCE, GRACE, terrestrial gravity data, and satellite altimetry (the EIGEN-6C model).

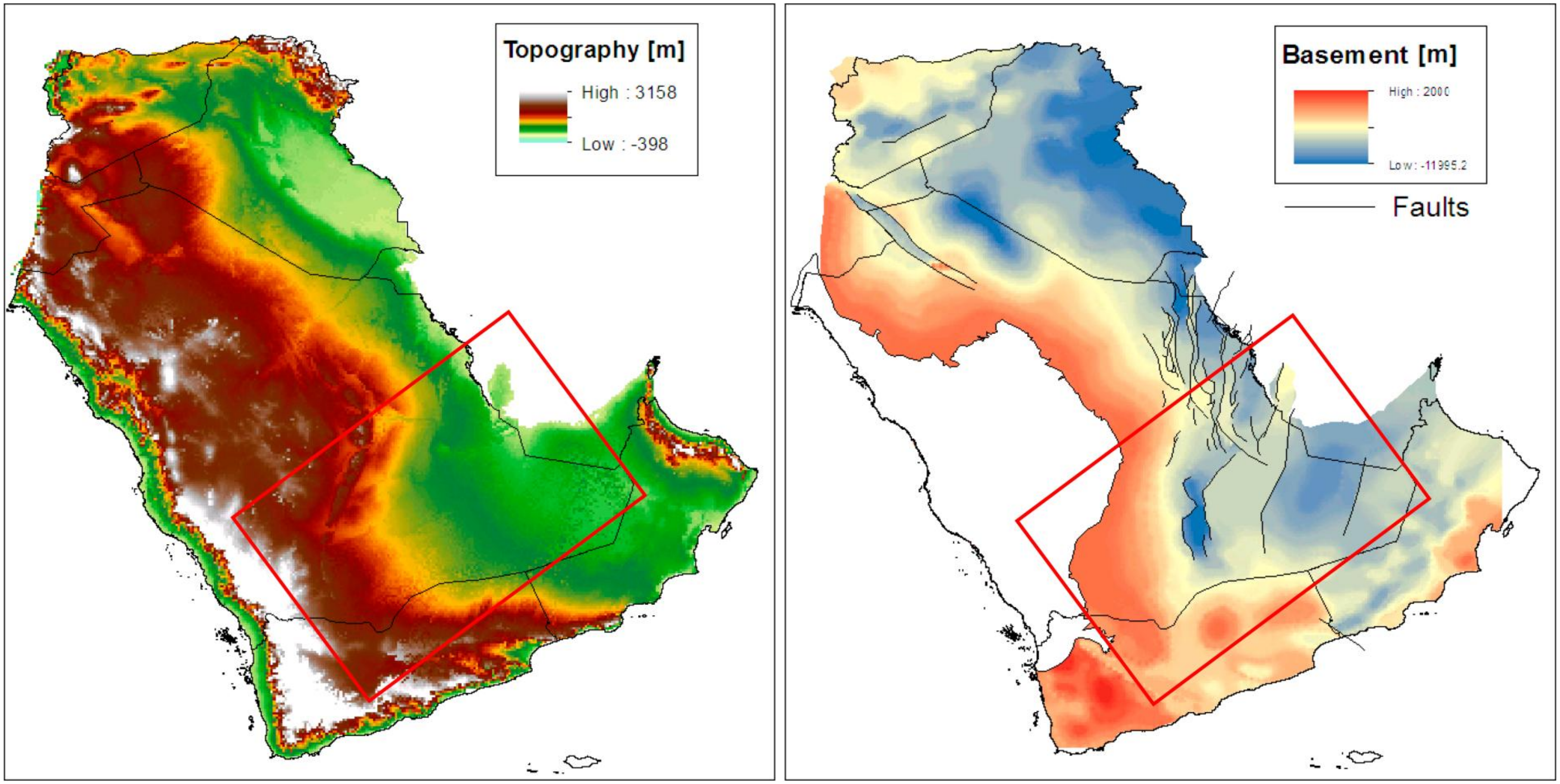

Figure 2. Topography of the Arabian Plate derived from SRTM elevation data (left panel). Depth to basement map (modified after Konert et al. 2001; right panel). These data are used to build the geological model.